

Responses to MAC#10 Recommendations

Vadim Ptitsyn

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+ Overview of eRHIC:

- Formulate a performance risk mitigation strategy.
 - To be done
- Continue the good work towards a realistic and plausible design.
 - At MAC#10 the FFAG eRHIC design with 10 GeV top electron energy was presented. Further exploration of the FFAG approach to electron beam recirculation convinced us that electron energy as high as 21 GeV could be reached with 2 (or 3) FFAG beamlines at reasonable cost.
The eRHIC Design study report has been published (arXiv:1409.1633) which contains a Chapter describing the accelerator design of 21 GeV FFAG electron accelerator. A journal version of this report is in preparation.
- Develop possible back-up plans in case CEC turns out to be less efficient than expected or the electron-beam current from the gun is lower than the design.
 - Cooling is a must for reaching $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ luminosity and satisfying detector requirements.
At lower than 50mA electron beam current the collider goals still can be reached with higher hadron beam intensity.

+ Overview

eRHIC Design Study An Electron-Ion Collider at BNL

Formulate a

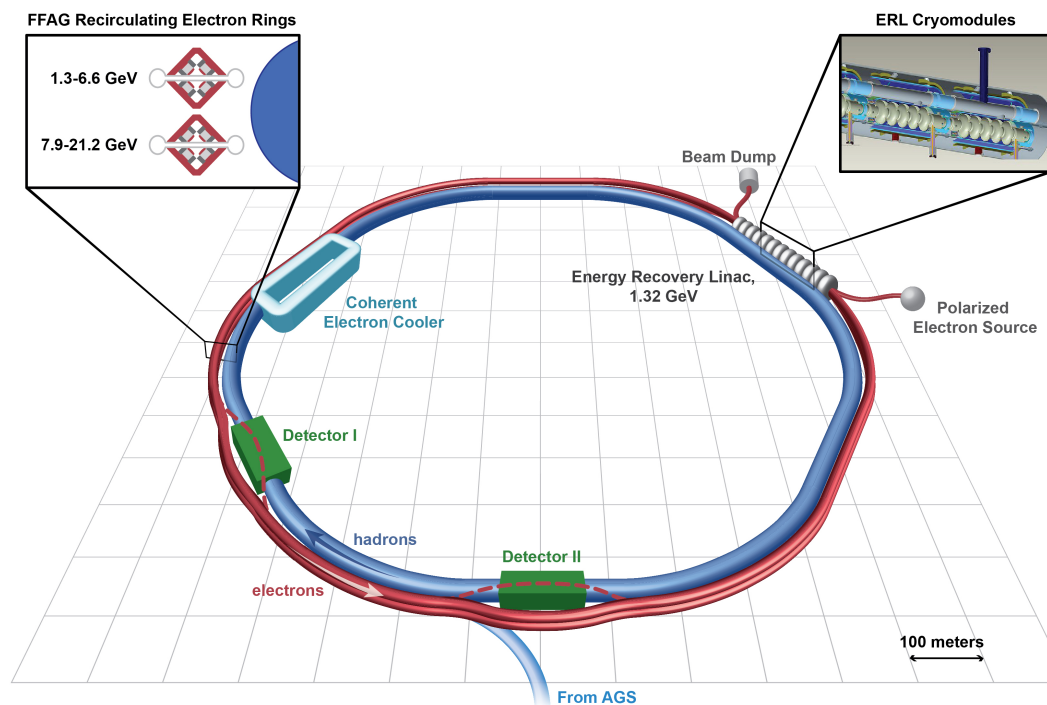
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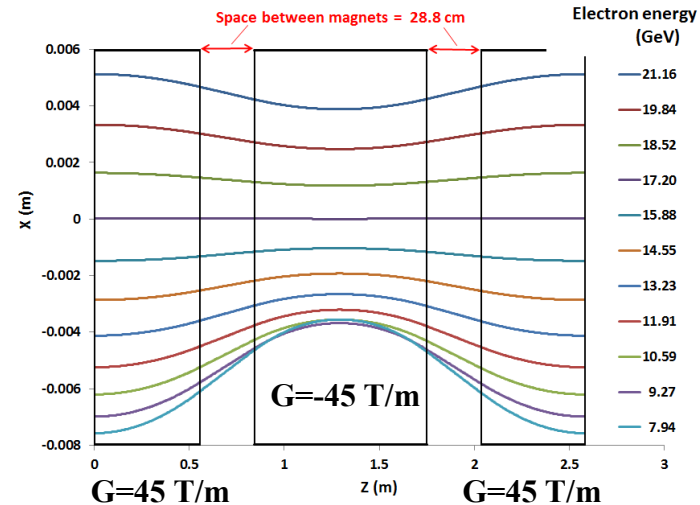


eRHIC Beam Parameters, Synchronization, and Polarization :

- Optimization is still required for the complete design.
 - Design optimization is continuing process, including cost factor.
- The electron spin tune does not cross the betatron tune, and thus spin diffusion is not expected. Nevertheless, it is advisable to include errors in quadrupole fields, and check whether there is an unfortunate random error that will give coherent spin kick. If so, then the possibility of compensation should be examined.
 - Initial studies of possible spin-lattice resonance effects have been done with ZGOUBI simulation code. No serious depolarization problem has been detected.
- Effects of the nonlinear field of the septum need to be evaluated (1) on the spin tracking in FFAG, (2) on the beam dynamics in general, and (3) on the colliding bunch in particular.
 - The effect of septum field will be included in the start-to-end simulations of electron beam transport which has began recently.

+ *The NS-FFAG Design of eRHIC :*

Mutli-energy transport
in eRHIC FFAG Cell:



- Further study of the effects of possible multipole components on beam stability and losses.
 - It will be subject of ongoing start-to-end simulation of electron beam transport.
- Detailed study of potential beam loss mechanisms and machine protection, the need for a collimation system.
 - So far, the electron beam loss due to Touschek and beam-gas scatterings has been evaluated. We plan to start more detailed studies of collimation system and machine protection in near future.

+ ***SRF ERL :***

- HOM study: This machine is a very high current one. Therefore, the HOM issue is the highest priority for the RF cavity design. The committee endorses the presented R&D plan for HOMs. It especially recommends soon starting a HOM study based on the BNL3 703.8 MHz 5-cell copper-model cavity.
 - LDRD funding has been approved for designing and prototype building of 422 MHz cavity (eRHIC ERL cavities). Further HOM studies will be carried out for this cavity.
- *Electropolishing*: The designed cavity assumes an extremely high Q and high gradient with 5 cells. The Committee recommends developing electropolishing as an alternative preparation technique, which is preferred for high gradient performance.
 - Applying alternative (to BCP) techniques is under evaluation, including electropolishing and N-doping.
- *Operating Temperature*: Although some paper studies suggest a 1.9 K operating point is cost effective the lack of a commercial refrigerator system significantly raises the price in comparison to a 2 K plant. Cost trade-offs using realistic hardware prices need to be performed before finalizing this design point.
 - This will be considered in the course of eRHIC cost estimate process, which is presently underway.



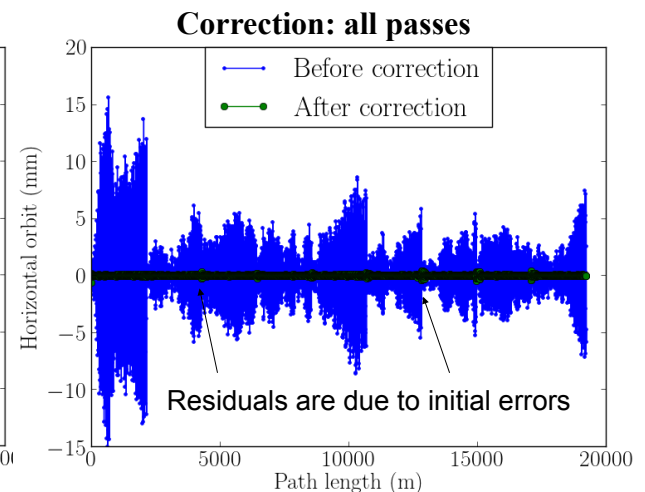
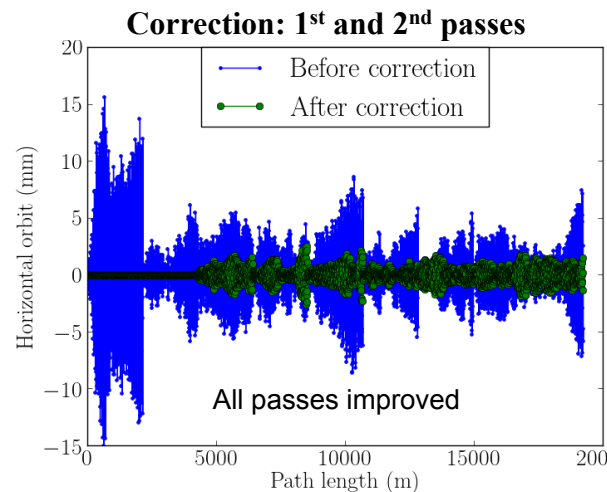
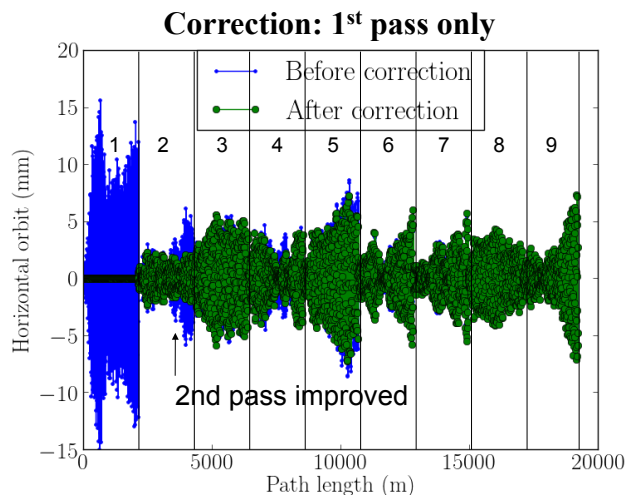
Tracking Results with Synchrotron Radiation and Misalignment:

- The most significant recommendation is for investigations to be started on the effect of magnetic field errors over all passes, including orbit stability and fractional beam losses.
- Realistic estimates of field quality have to be obtained. Once this has been done, the estimates have to be incorporated into the tracking.
- One anticipates that (uncompensated) field errors will cause unacceptable closed orbit deviation. As discussed by Liu there are tentative plans for measuring and compensating field errors, even in the face of multiple beams being detected in the same BPM's. Testing and refinement of such compensation schemes will be another essential task for tracking programs.
- The magnitude and description of nonlinear field errors and the effect of nonlinear resonances over 11 turns deserves both theoretical and numerical investigation. Multipole field expansions should be performed around each individual orbit.
 - The start-to-end simulations using several available codes (ELEGANT, ZGOUBI, MUON) have being started. They will address all recommendations listed above. One of the primary goals of the simulations is to establish limits on the acceptable lattice chromaticity (the large chromaticity coupled with the orbit errors creates a mechanism for the transverse emittance growth).



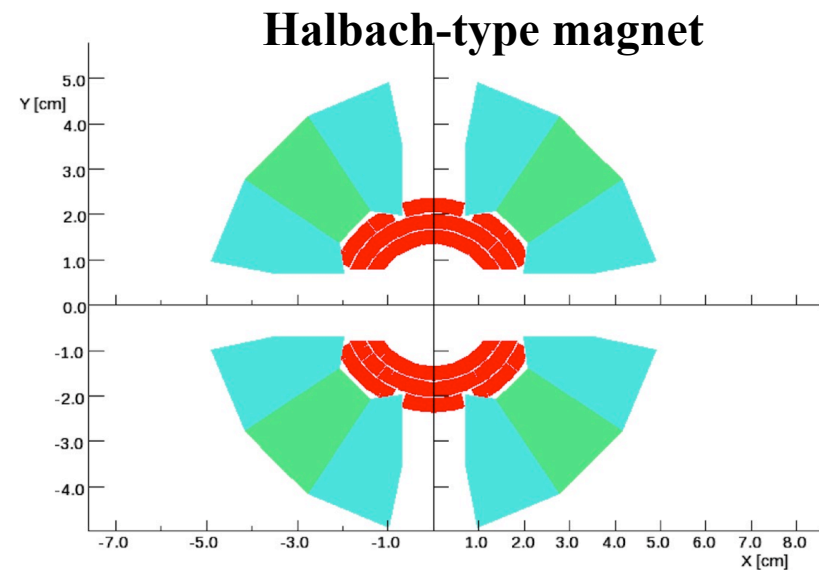
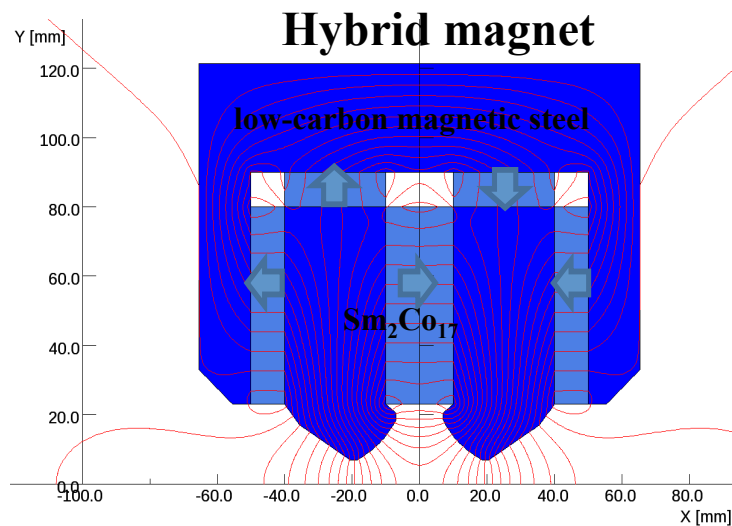
Orbit Correction with Misalignment and Gradient Errors:

- Continue along this approach increasing detail as the design becomes more fully developed. As the spreaders and recombiners become better defined include them in the error analysis to assure the beam stays within orbit acceptance and the necessary control is within required ability to measure and to feed-back on, using planned diagnostic capability.
- We continue to study and refine the orbit correction of FFAG transport (number of BPMs and correctors, effect of chromaticity,...). Dispersion function measurement and control is also currently under study.



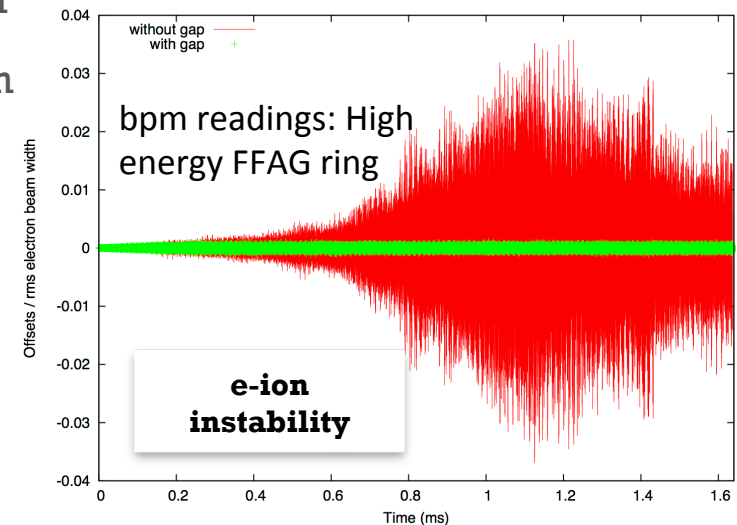
+ Magnet Design:

- Obtain specifications on the higher field harmonics from the eRHIC beam dynamics group and perform comparative analysis of the magnet field quality all over the FFAG orbit range in 3D, including edge effects.
- One round of simulations with ZGOUBI to evaluate initial tolerances on the high field harmonics has been done. (Tolerances are at the level few units 10^{-4} at 1cm). More thorough simulation studies are on-going.
- Build a prototype magnet and measure the field quality and temperature stability.
 - Permanent magnet prototypes (for 3-4 possible designs) will be built in 2015.



+ *Collective Effects:*

- Simulations for the fast ion instability in the arcs could be performed considering all passing bunches, at different transverse positions, and with different beam sizes. The assumed residual-gas pressure should be confirmed by calculations for a realistic design of the vacuum system.
 - The simulation code evaluating the beam-ion dynamic has been upgraded to include all mentioned features. Initial cycle of simulation has been done.
- Resistive-wall simulations should be performed considering a flat vacuum chamber including quadrupole wake fields.
- A possible 2-bunch head-tail effect, and enhanced beam break up, should be examined for the turn where leading accelerating and trailing decelerating bunch, separated by half an RF wavelength, have the same energy.
- Joint simulations of beam break up together with beam-beam collisions should be performed.
 - All yet to be done.



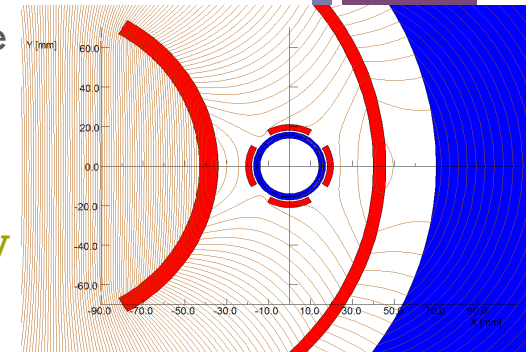


Instrumentation & Commissioning :

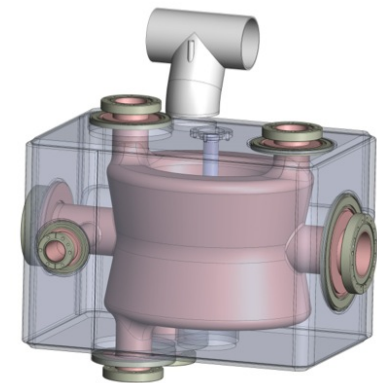
- Continue to pursue development of the specially adapted diagnostics taking advantage of any means to clearly provide the identification and position resolution needed for both the accelerating and decelerating beams. This is an area where a modest program of R&D may be highly beneficial to the program.
- Build a test rig and simulate performance of the bunch by bunch BPM.
 - LDRD funding for design and prototyping the stripline BPM to distinguish closely separated bunches has been approved.
- Continue commissioning planning to identify any holes in initiation of the full power beam which may be filled through appropriate setup techniques or the addition of key instruments in critical locations.
 - To be done.

+ *IR Design and Hadron Lattice:*

- The study presented so far is preliminary IP conceptual design. The dynamic aperture is also preliminary. More work is needed to optimize the IR design.
 - IR design presented at MAC#10 has been modified. Modified design employs new ideas (B.Parker) of arranging electron field-free pass through the SC coil area of hadron magnets. New design has not been fully completed yet. DA studies are still to be done.
- Committee members are not fully convinced that betatron wave created in the arc will provide a better high order chromatic aberration.
- The electron interaction region needs to be designed and the effects mentioned above evaluated.
 - The initial design of electron beamline has been developed.
- Detailed design of the crab cavity systems is necessary.
 - Beam dynamics studies to better understand tolerances for crab cavity system are planned.
 - The cavity design will follow the DQWR crab cavity developed for LHC upgrade.



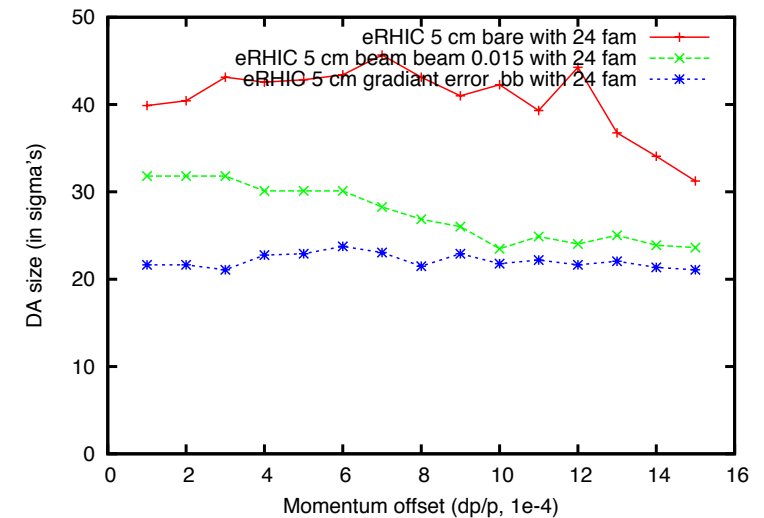
e-beam passage arranged at “sweet” spot between SC coils



BNL crab-cavity prototype for HL-LHC

+ *Dynamic Aperture:*

- In addition to chromaticity correction and resonance driving terms, it should be checked whether the dynamic aperture could be improved by minimizing tune- dependences on actions up to second order.
- DA optimization method, as well as the sextupole correction scheme have been improved. The solution has been found which provides 20σ DA up to 0.15% energy deviation. However, modified IR design is more challengeable (larger beta_max). The DA optimization for the modified IR design has not started yet.



- Further studies to optimize tune values and generate suitably matched lattices are necessary, in particular for the ATS optics.

■ To be done.

- Profit from crab cavity tests planned in SPS and LHC.

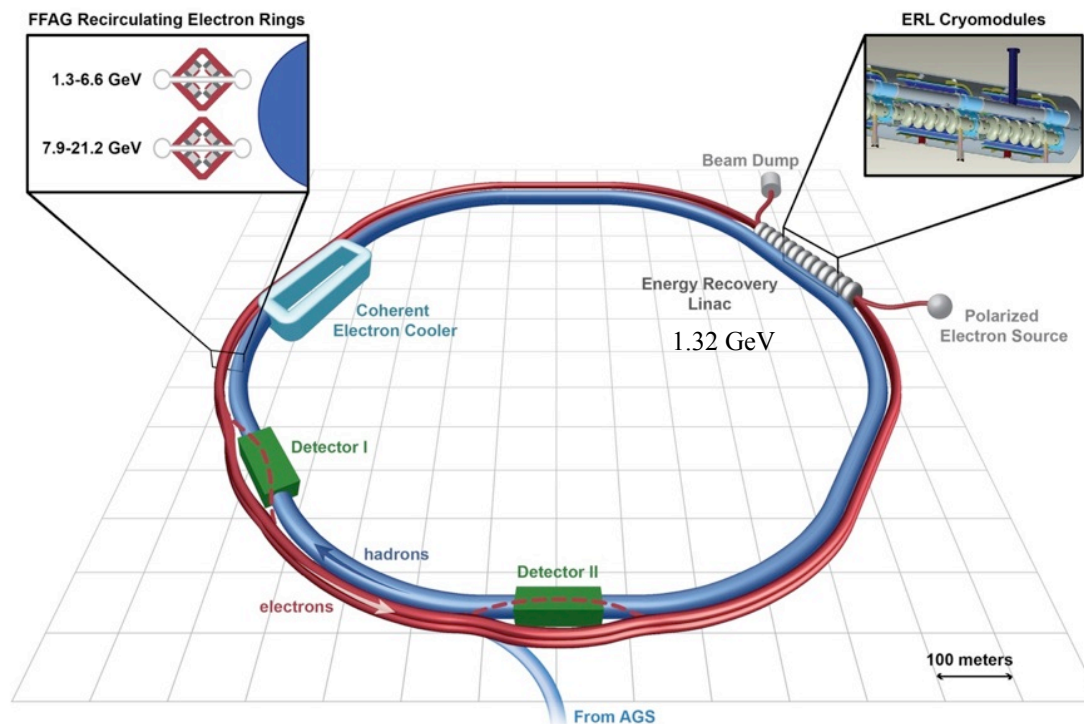
■ We definitely will. Our SRF group members will participate in those tests.

+ ***Beam-Beam:***

- Perform beam-beam experiments using the CeC electron beam to study beam disruption, noise properties, and kink instability.
 - Experiments are in preparation stage; following commissioning of the CeC device. (See V. Litvinenko's presentation)

FFAG eRHIC Design

- ✧ Up to 21.2 GeV electron beam accelerated with Energy Recovery Linac (ERL) inside existing RHIC tunnel collides with existing 250 GeV polarized protons and 100 GeV/n HI RHIC beams
- ✧ Single collision of each electron bunch allows for large disruption, giving high luminosity and full electron polarization transparency
- ✧ Use 2 FFAG magnet strings in RHIC tunnel to transport up to 16 beams
- ✧ Considered permanent magnet design for FFAG lattice magnets
- ✧ Cool hadron beam 10-fold in all directions using coherent electron cooling (CeC) at reduced intensity of hadron beam
- ✧ IR design with $\beta^* = 5$ cm using SC magnet technology and crab-crossing scheme
- ✧ Average polarized electron current of 50 mA



$$L = 10^{33} - 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$$

+ eRHIC R&D Activities

- Prototyping of Gatling Gun polarized electron source (preparations for beam tests)
- Coherent electron Cooling PoP using 40 GeV/n Au beams in RHIC (e-source commissioning)
- High average current ERL to support operation with high current e-beam (e-source commissioning, first beam current has been extracted)
- Prototype ERL with FFAG arcs @ Cornell (White paper is being developed)
- High gradient crab cavities within LARP (prototype testing at SPS)
- Development of polarized He-3 (underway in collaboration with MIT)

